Double-Chooz: a search for θ_{13}

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The Double-Chooz experiment goal is to search for a non-vanishing value of the θ_{13} neutrino mixing angle. This is the last step to accomplish prior moving towards a new era of precision measurements in the lepton sector. The current best constraint on the third mixing angle comes from the CHOOZ reactor neutrino experiment $\sin(2\theta_{13})^2 < 0.2$ (90% C.L., $\Delta m^2_{atm} = 2.0$ eV^2). Double-Chooz will explore the range of $\sin(2\theta_{13})^2$ from 0.2 to 0.03-0.02, within three years of data taking. The improvement of the CHOOZ result requires an increase in the statistics, a reduction of the systematic error below one percent, and a careful control of the backgrounds. Therefore, Double-Chooz will use two identical detectors, one at 150 m and another at 1.05 km distance from the Chooz nuclear cores. In addition, we will to use the near detector as a "state of the art" prototype to investigate the potential of neutrinos for monitoring the civil nuclear power plants. The plan is to start operation with two detectors in 2008, and to reach a sensitivity $\sin^2(2\theta_{13})$ of 0.05 in 2009, and 0.03-0.02 in 2011.

1. The Chooz experimental site

The experimental site is located in the Ardennes (France), close to the Chooz nuclear power plant, operated by the French company Electricite de France (EDF). There are two N4 type PWR reactors of 4.27 GW$_{th}$ each. We will use two almost identical detectors, containing a fiducial volume of 10 tons of liquid scintillator doped with 0.1% of Gadolinium (Gd). The laboratory of the first CHOOZ experiment, located 1.05 km (the *Chooz-far* site, overburden of 300 m.w.e.) from the cores will be used again. This is the main advantage of this site. In order to cancel the systematic errors originating from the nuclear reactors ($\overline{\nu_e}$ flux and energy spectrum), as well as to reduce the systematic errors, a second detector will be installed close to the nuclear cores (the *Chooz-near* site). Since no natural hills or underground cavity already exists at this location, an artificial overburden of about 20 meters height has to be built. At 150 m the required overburden to protect the detector from cosmic ray induced backgrounds is 60 m.w.e..

2. The new detector concept

The detector design is an evolution of the detector of the first experiment [1]. To improve the sensitivity of Double-Chooz with respect to CHOOZ it is planned to increase statistics and to reduce and better control the systematic errors and backgrounds. In order to increase the exposure to 60,000 events at Chooz-far (statistical error of 0.4%) it is planned to use a target cylinder of 120 cm radius and 280 cm height, providing a fiducial mass of 10 tons (12.7m^3), 2.3 times larger than in CHOOZ. In addition, the data taking period will be extended to at least three years, and the overall data taking efficiency will be improved. The near and far detectors will be identical inside the PMT supporting structure. This will allow a relative normalization systematic error of 0.6%. Starting from the center of the target the detector elements are as follows (Figure 1). The neutrino target: A 120 cm radius, 280 cm height, 8 mm thick acrylic cylinder, filled with 0.1% Gd loaded liquid scintillator. The baseline of the scintillator being developed for the new experiment is a mixture of 20% of PXE and 80% of dodecane, with small quantities of PPO and bis-MSB added as fluors. The γ-catcher: A 60 cm buffer of liquid scintillator not loaded with Gd, with the same light yield as the target. The role of this *new* region is to get the full positron energy, as well as most of the neutron energy released after neutron capture. It is enclosed in a 180 cm radius,

400 cm height, 10 mm thick acrylic cylinder. The non scintillating buffer: A 95 cm buffer of non scintillating oil, to decrease the level of accidental background (mainly the contribution from photomultiplier tubes radioactivity from potassium, uranium and thorium) and the PMT supporting structure. The outer veto: A 60 cm veto region filled with liquid scintillator for the far detector, and a slightly larger one (about 100 cm) for the near detector. The external shielding: A 15 cm steel shielding surrounding the far detector, and a $\sim$1 m low radioactive sand or water layer for the near detector.

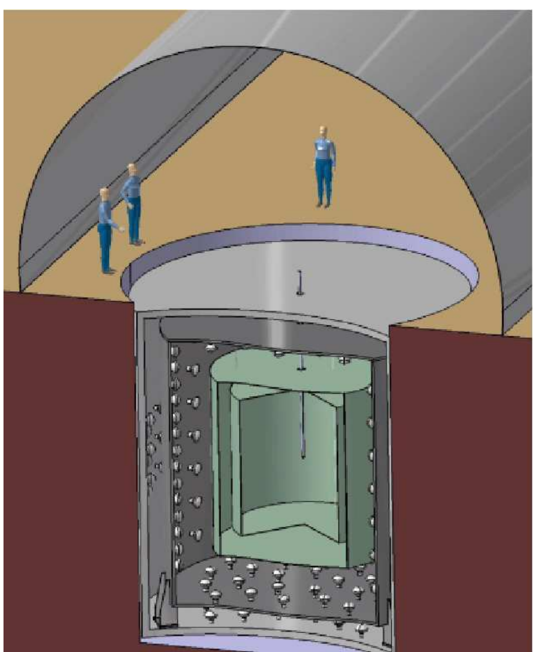

Figure 1. The detector is located in the tank used for the CHOOZ experiment (7 meters high and diameter). About 10 tons of a liquid scintillator doped with Gd is contained in a double-acrylic cylinder surrounded by the gamma-catcher region, the buffer and the muon veto. The optical coverage of the PMTs is about 15%.

We plan to build the double acrylic vessels at the manufacturer and transport it to the detector sites in a single piece. This integration procedure allow us to minimize the differences between the acrylic vessels as well as to reduce the residual mechanical stress that could favor the acrylic crazing.

3. Systematic errors and backgrounds

In the first CHOOZ experiment, the total systematic error amounted to 2.7%. Thanks to the use of the double detector concept, each error originating from the neutrino source, e.g. the reactors, cancels. Thus we can neglect the “reactor cross section error” of 1.9%, the uncertainty on the reactor power of 0.7%, as well as the lack of knowledge of the energy released per fission of 0.6%. The dominant error for Double-Chooz will thus be the relative normalization between the two detectors; it originates for instance from the detection efficiency, or a difference in the number of free protons contained in the acrylic targets. We focus our efforts towards the precise measurement of the relative volumes between the acrylic targets, and the dead time measurement. In addition, the position of the near detector with respect to the core will have to be measured with a precision better than 10 cm. In Double-Chooz, we estimate the total systematic error on the normalization between the detectors to be less than 0.6%. The main contributions come from the solid angle (0.2%), the volume (0.2%), the density and H/C ratio (0.15%), the neutron detection efficiency and energy measurement (0.2% and 0.1%), the e^+-n time delay (0.1%) and the dead time (0.25%, with a new method of fake triggers generated inside the target under development).

The signature for a neutrino event is a prompt signal with a minimal energy of about 1 MeV and a delayed 8 MeV signal after neutron capture by a Gd nucleus. This may be mimicked by background events which can be divided into two classes: accidental and correlated events. The former can be reduced by a careful selection of the materials used to build the detector. In addition this background is easy to measure in-situ, and its subtraction lead to a small systematic error. A

comprehensive Monte-Carlo study shows that the correlated events are the most severe background source for the experiment. Our simulation reproduced fairly well the correlated background rate measured in the first CHOOZ experiment and is thus reliable. Two processes mainly contribute: β-neutron cascades and very fast external neutrons. Both types of events are coming from spallation processes of high energy muons. In total the background rates for the near detector will be between 9/d and 23/d, for 60 m.w.e. overburden. For the far detector a total background rate between 1/d and 2/d can be estimated. This can be compared with the signal of $\sim$ 4000/d and 80/d in the near and far detectors. The overburden of the near detector has been chosen in order to keep the signal to background ratio above 100. Under this condition, even a knowledge of the backgrounds within a factor two keeps the associated systematic error below the percent.

4. Discovery potential

The Double-Chooz experiment is searching for a deficit in the $\overline{\nu_e}$ flux at 1.05 km from the cores, while the near detector monitors the $\overline{\nu_e}$ flux and energy spectrum prior to any neutrino oscillation. This disappearance channel allows a “clean” measurement of $\sin(2\theta_{13})^2$. Assuming a relative normalization error of 0.6%, and three years of data taking with typical live time for both reactor and detector operations, the sensitivity will be $\sin(2\theta_{13})^2 < 0.025$ (at 90% C.L., for $\Delta m^2_{atm} = 2.4$ eV^2) in the case of no-oscillation. The discovery potential with a so-called “3-σ” effect will be around 0.04. For a true value $\sin(2\theta_{13})^2$=0.1 a rate only analysis will reject the no-oscillation scenario at 2.6σ, whereas a shape+rate analysis will reject the no-oscillation scenario at about 6σ. This clearly shows that the shape distortion could be used as a smoking gun in Double-Chooz. For a true value $\sin(2\theta_{13})^2$=0.1, Double-Chooz would perform a measurement of the oscillation parameter with a 67% relative error (90% C.L.); this can be compared with the potential of 100-130% of the complementary superbeam experiments.

5. Double-Chooz and non-proliferation

Recently, the International Atomic Energy Agency (IAEA) expressed the interest to use antineutrinos as a tool to verify the non-proliferation of nuclear weapons. A detector close to a nuclear plant, like Double-Chooz-near, could provide “remote” and non-intrusive measurements of plutonium content in reactors, since the antineutrino flux and energy spectrum depend upon the thermal power and the fissile isotopic composition of the reactor fuel. A part of the Double-Chooz collaboration is planing new measurements of the spectrum of various fissile elements in order to reduce the error of the neutrino spectrum emitted by a nuclear core. For that purpose, a new $\beta-$spectrometer is being studied to upgrade the Mini-Inca instrument, at the ILL research reactor in Grenoble (France). Furthermore, the upgrade of the monitoring system of the thermal power is under study; this could allow a better monitoring of the $\overline{\nu_e}$ flux, and to measure the position of the source barycenter within a few centimeters.

6. Outlooks

The Double-Chooz collaboration is composed of about 16 institutes (in France, Germany, Italy, Russia and USA). A Letter of Intent has been released in may 2004 [2], and the experiment has been approved in France. The funding of the near laboratory in partnership with the EDF power company and the local authorities is currently being discussed. If fully approved in 2005, it is intended to start taking data at Chooz-far in 2007, and at Chooz-near in 2008. If the collaboration meets this goal, Double-Chooz could provide a sensitivity limit of $\sin(2\theta_{13})^2 < 0.05$ (at 90% C.L.) within the year 2009, and 0.02-0.03 in 2011.

REFERENCES

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